Iowa Water Center
Annual Technical Report
FY 2015

Introduction

The Iowa Water Center celebrated its tenth year with Dr. Richard Cruse as director during this project year. Successful 104b and information transfer projects guided the continued stability of the Center in FY2015, and paved the way to allow the Center to undergo expansion in FY2016.

Research Program Introduction

The FY2015 projects funded through the 104(b) competitive seed grant programs were continuations of projects previously funded in FY2014. These two projects have yielded important results that have resulted in additional funded awards from the National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, and the US Army Corps of Engineering.

Validation of Satellite Observations of Soil Moisture to Facilitate Forecasts of Soil Water Storage in Iowa

Basic Information

Title:	Validation of Satellite Observations of Soil Moisture to Facilitate Forecasts of Soil Water Storage in Iowa
Project Number:	2014IA252B
Start Date:	3/1/2014
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	IA - 004
Research Category:	Climate and Hydrologic Processes
Focus Category:	Agriculture, Drought, Water Quantity
Descriptors:	None
Principal Investigators:	Brian Hornbuckle

Publications

1. Hornbuckle, B. K., New Satellites for Soil Moisture: Good for Iowans! Getting Into Soil and Water: 2014, p20-22, D.C. McDonough, Ed., Iowa Water Center, Ames, IA, 2014.
2. Rondinelli, W.J., B. K. Hornbuckle, J. C. Patton, M.H. Cosh, V.A. Walker, B.D. Carr, and S.D. Logsdon, Different Rates of Soil Drying After Rainfall are Observed by the SMOS Satellite and the South Fork In Situ Soil Moisture Network, Journal of Hydrometeorology, doi: 10.1175/JHM-D-14-0137.1, 2015.
3. Hornbuckle, B. K., J. C. Patton, A. VanLoocke, A. E. Suyker, M. C. Roby, V. A. Walker, E. R. Iyer, D. E. Herzmann, and E. A. Endacott, SMOS Optical Thickness Changes in Response to the Growth and Development of Crops, Crop Management, and Weather, Remote Sensing of Environment, Special Issue on ESA's Soil Moisture and Ocean Salinity Mission – Achievements and Novel Applications after 5 Years in Orbit, 10.1016/j.rse.2016.02.043, 2016.

Validation of Satellite Observations of Soil Moisture to Facilitate Forecasts of Soil Water Storage in Iowa *

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Focus Categories: Agriculture (AG);
Drought (DROU); Water Quantity (WQN).

Research Category: Hydrology (HYDROL).

Keywords: soil moisture; satellite remote sensing; weather forecasting; climate prediction; agriculture.

Duration of Project: 2 years, June 1, 2014, to May 31, 2016.

Congressional District: Iowa District 4

May 31, 2016

*Progress report for the period 3/1/15 - 2/29/16.

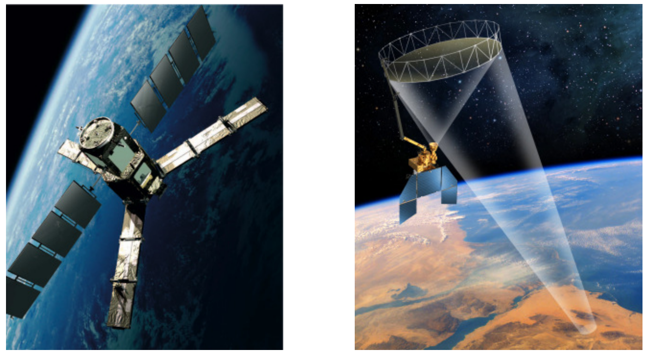

Figure 1: At left, the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite. At right, NASA's Soil Moisture Active Passive (SMAP) satellite.

1 Problem and Research Objectives

Soil moisture is the reservoir of water that supports agriculture and consequently much of the human race. Soil moisture also affects the amount and variability of precipitation and hence the occurrence of flooding and drought.

Remote sensing satellites that observe near–surface soil moisture have recently been deployed (Figure 1). The European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite mission was launched in late 2009, and NASA's Soil Moisture Active Passive (SMAP) satellite mission was launched in early 2015.

Before measurements of near–surface soil moisture made from space can be used to estimate the amount of water stored in the soil and improve weather and climate predictions, the quantitative value of the measurements must be known. In other words, the satellite observations must be compared to a standard or what is considered the "truth" through a process known as validation.

Our research objectives for this project are as follows.

- Validate and then, if necessary, improve SMOS observations of near–surface soil moisture in Iowa.
- Initiate the validation of SMAP observations of near–surface soil moisture observations in Iowa.

2 Methodology

We will use a network of in situ soil moisture measurements located in the watershed of the South Fork Iowa River as the validation standard for both SMOS and SMAP. The network consists of 20 nodes. At each node soil moisture is measured in situ with buried instruments that relate the electrical properties of the soil to volumetric water content. Other relevant measurements such as soil temperature and precipitation are also made at each node.

Along with the permanent measurements of soil moisture, periodic measurements with hand–held devices are made to calibrate the buried instruments to the soil type of the area

automated soil moisture measurements

in-situ calibration referenced to gravimetric soil moisture

Figure 2: At left, in–situ automated soil moisture sensors. At right calibration of a Theta Probe to a gravimetric reference.

and to scale them to better represent the soil moisture conditions of a larger area. Pictures of these instruments are shown in Figure 2.

Both the SMOS and SMAP missions are striving to meet the same precision metric, which is a root–mean–square–error (RMSE) of less than 0.04 m^3 m^{-3} in observations of near–surface volumetric soil moisture.

3 Principle Findings and Significance

We have found that SMOS soil moisture observations are noisy and have a dry bias as compared to the South Fork network. See Figure 3. The unbiased RMSE of the satellite observations is about 0.06 m^3 m^{-3} (0.07 m^3 m^{-3} in 2013, 0.06 m^3 m^{-3} in 2014, and 0.06 m^3 m^{-3} in 2015) which is larger than the mission goal. Average bias (South Fork minus SMOS) is 0.07 m^3 m^{-3} (0.06 m^3 m^{-3} in 2013, 0.07 m^3 m^{-3} in 2014, and 0.09 m^3 m^{-3} in 2015).

We will test several hypotheses that could explain why SMOS is noisy and "dry" as compared to the South Fork network.

1. Incorrect surface temperature used in the soil moisture retrieval model.
2. Radio–frequency interference (RFI) from anthropogenic sources emitting radiation in the band of wavelengths measured by SMOS.
3. Soil texture in the SMOS global database that does not match the actual soil characteristics in the South Fork. After soil moisture, vegetation, and surface temperature, soil texture has the largest impact on SMOS measurements.
4. Land cover in the SMOS global database does not match what is on the ground in the South Fork. Vegetation is the single most important factor that must be taken into account in order to retrieve soil moisture.

Once we determine the problem, we will attempt to implement an improved soil moisture retrieval algorithm.

We tested the first hypothesis in the first year of the project and found that it could not explain the dry bias.

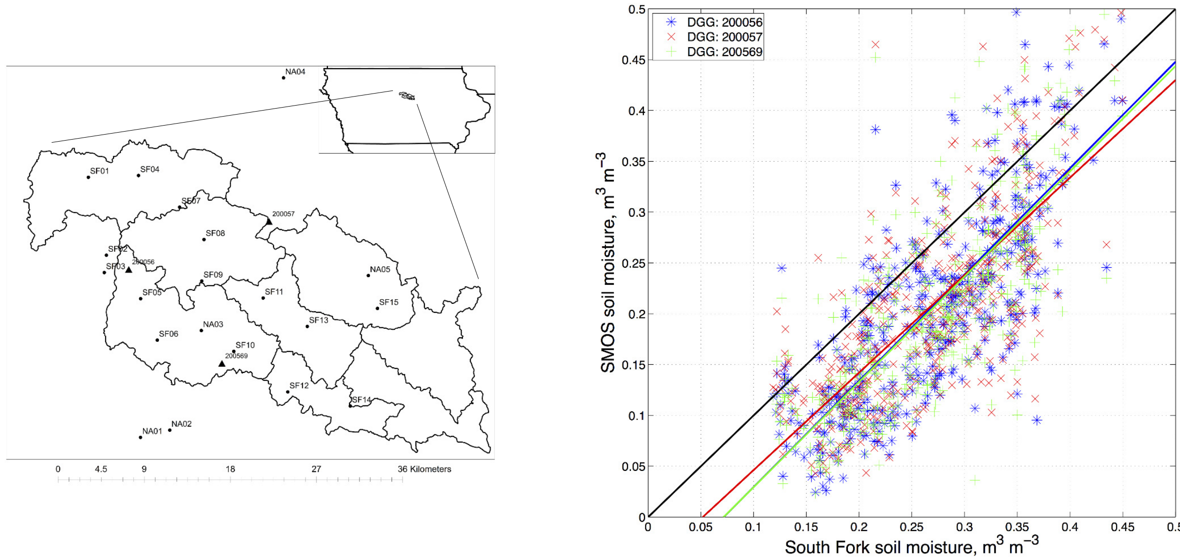

Figure 3: At left, the locations of the 20 nodes of a network of in–situ automated soil moisture sensors in the watershed of the South Fork Iowa River. At right, a comparison of SMOS soil moisture observations from the three closest SMOS pixels (DGGs 200056, 200057, 200569) and the average network soil moisture.

We have completed testing the second hypothesis. We compared morning (6 am) and evening (6 pm) SMOS observations separately with the South Fork network. If RFI is present, then there should be a significant difference in the statistics of morning and evening observations since SMOS is "looking" at Earth's surface at a different orientation relative to the surface. Any anthropogenic sources of radiation will, by definition, have a specific directional nature. Our analysis suggests that RFI is not present since there is little difference between morning and evening observations in terms of bias (0.07 and 0.08 m^3 m^{-3}, respectively) and unbiased RMSE (0.06 m^3 m^{-3} for both morning and evening).

We also completed testing the third hypothesis. A new soil textural map was implemented by the SMOS mission in May 2015. The old and new soil maps for the South Fork are shown in Figure 4. Note that the old soil map assumed a clay fraction of 0.4 across the entire domain. The new soils map has a much more realistic spatial variation that accounts for an ancient lake on the west side of the domain. In addition, the new soils map has a much lower clay fraction overall. According to the data in the bottom half of Figure 4, using a higher clay fraction results in *wetter* soil moisture retrievals. Hence the new soil map may actually be responsible for the larger dry soil moisture bias that was observed in 2015 as compared to the previous two years. While this overall result is not desirable, using a more realistic soil map is definitely a step in the right direction. In summary, incorrect soil texture is not the source of the dry soil moisture bias, and a new (and more realistic) soil map likely made the bias larger in 2015.

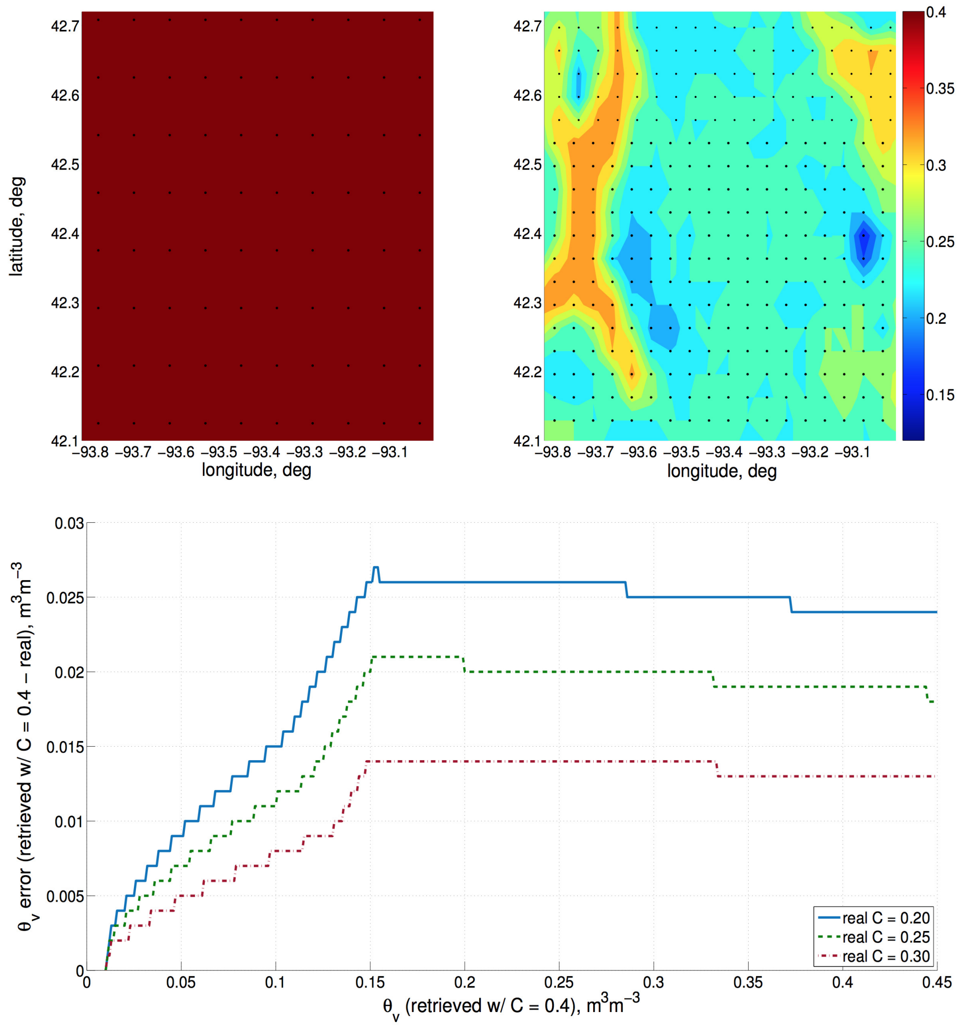

Figure 4: Upper left: old soil map of clay fraction (0.4 across entire South Fork network) used by SMOS. Upper right: new soil map of clay fraction currently used by SMOS starting May 2015. Bottom: error in retrieved soil moisture caused by using old soil map.

4 Notable Achievements or Awards

None.

5 Student Support

The funding for this project is supporting the work of Victoria Walker, a graduate student at Iowa State University working towards the master of science degree in agricultural meteorology. Erik Endacott, a first–year undergraduate student in the honors program at Iowa State, worked for the Fall 2015 semester on the project and earned academic credit.

6 Publications

1. Hornbuckle, B. K., J. C. Patton, A. VanLoocke, A. E. Suyker, M. C. Roby, V. A. Walker, E. R. Iyer, D. E. Herzmann, and E. A. Endacott, SMOS Optical Thickness Changes in Response to the Growth and Development of Crops, Crop Management, and Weather, *Remote Sensing of Environment, Special Issue on ESA's Soil Moisture and Ocean Salinity Mission – Achievements and Novel Applications after 5 Years in Orbit*, 10.1016/j.rse.2016.02.043, 2016.

Development of a Framework for Discharge Forecasting over Iowa

Basic Information

Title:	Development of a Framework for Discharge Forecasting over Iowa
Project Number:	2014IA253B
Start Date:	3/1/2014
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	IA-002
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Hydrology, Floods
Descriptors:	None
Principal Investigators:	Gabriele Villarini

Publications

1. Karlovits, G.S., G. Villarini, A.A. Bradley, and G.A. Vecchi, Diagnostic evaluation of NMME precipitation and temperature forecasts for the continental United States, 95th American Meteorological Society Annual Meeting, Phoenix, Arizona, January 4-8, 2015.
2. Karlovits, G.S., G. Villarini, A. Bradley, and G.A. Vecchi, Diagnostic evaluation of NMME precipitation and temperature forecasts for the continental United States, AGU Fall Meeting, San Francisco, California, December 15-19, 2014.
3. Villarini, G., Seasonal discharge forecasting over Iowa: Preliminary results for the Raccoon River, Iowa Water Conference, Ames, IA, March 2-3, 2015.
4. Slater, L.J., G. Villarini, and A.A. Bradley, Evaluation of the skill of North-American Multi-Model Ensemble (NMME) global climate models in predicting average and extreme precipitation and temperature over the continental USA, submitted to Climate Dynamics, 2016.
5. Slater, L.J., G. Villarini, A.A. Bradley, and G.A. Vecchi, A statistical/dynamical framework for seasonal streamflow forecasting in an agricultural watershed, submitted to Climate Dynamics, 2016.
6. Slater, L., G. Villarini, A. Bradley, and G.A. Vecchi, Seasonal forecasting of discharge for the Raccoon River, Iowa, General Assembly, EGU, Vienna, Austria, April 17-22, 2016.
7. Villarini, G., L. Slater, and K. Salvi, Discharge forecasting for the Raccoon River at Van Meter, Iowa: From next season to the next decade, Environmental and Water Resources Conference, Ames, Iowa, April 7, 2016.
8. Villarini, G., and L. Slater, Seasonal forecasting of discharge for the Raccoon River at Van Meter, Iowa, Iowa Water Conference, Ames, Iowa, March 24, 2016.
9. Slater, L., G. Villarini, and A. Bradley, Diagnosis of North American Multi-Model Ensemble (NMME) skill for predicting floods and droughts over the continental USA, AGU Fall Meeting, San Francisco, California, December 14-18, 2015.

Problem and Research Objectives

Iowa is plagued by catastrophic natural hazards on a yearly basis, with the 2008 flood and the 2012 drought being two of the most recent extreme events affecting our state. Unfortunately, the question is not if, but when, the next extreme event will happen. There is little we can do to prevent flooding or droughts but we can improve our preparedness for these events. Improved readiness relies on the availability of information that would allow Iowans to make more informed decisions about the most suitable water management strategy. The proposed work aims to develop a framework to provide seasonal forecasts of discharge over Iowa with a lead time from one up to nine months. The availability of these forecasts would have major societal and economic impacts on hydrology and water resources management, agriculture, disaster forecasts and prevention, energy, finance and insurance, food security, policy-making and public authorities, and transportation.

Methodology

This proposal will advance our preparedness for flood and drought conditions over Iowa. Our approach aims at the development of a forecasting system to provide seasonal discharge values for one watershed in Iowa (Raccoon River at Van Meter). The methodology leverages the use of statistical models to describe discharge from low to high flow as described in Villarini and Strong (2014). These models use rainfall as well as row crop production acreage (used as a proxy for the characterization of the impacts of agricultural practices) as inputs. Seasonal rainfall forecasts will be based on one coupled ocean-atmosphere model, while the forecast of row crop production will be based on the value from the previous year (persistence forecast). The discharge forecast will have a lead time from one to up to nine months.

Principal Findings and Significance

Over the past year we have been making very significant progress towards accomplishing what proposed for this project, as documented in two manuscripts currently under review (Slater et al. 2016a, b). We have downloaded and processed temperature and precipitation forecasts from eight Global Climate Models (GCMs) from the North-American Multi-Model Ensemble (NMME; Kirtman et al. 2014) project (CCSM3, CCSM4, CanCM3, CanCM4, GFDL2.1, FLORb01, GEOS5, and CFSv2).

In the first study (Slater et al. 2016a), we have quantified the skill of the monthly forecasts across the continental United States using the mean square error skill score. This score is decomposed to assess the accuracy of the forecast in the absence of biases (potential skill) and in the presence of conditional (slope reliability) and unconditional (standardized mean error) biases. We have summarize the forecasting skill of each model according to the initialization month of the forecast and lead time, and test the models' ability to predict extended periods of extreme climate conducive to eight 'billion-dollar' historical flood and drought events.

Our results indicate that the most skillful predictions occur at the shortest lead times and decline rapidly thereafter. Spatially, the potential skill varies little, while actual model skill scores exhibit strong spatial and seasonal patterns primarily due to the unconditional biases in the models. The conditional biases vary little by model, lead time, month, or region. Overall, we have found that the skill of the ensemble mean is equal to or greater than that of any of the individual models. At the seasonal scale, the drought events are better forecasted than the flood events, and are predicted equally well in terms of high temperature and low precipitation. Overall, our findings have provided a systematic diagnosis of the strengths and weaknesses of the eight models over a wide range of temporal and spatial scales.

In the second study (Slater et al. 2016b), we have described the results related to the development of a statistical-dynamical prediction framework providing probabilistic seasonal streamflow forecasts ranging from low to high flows for the Raccoon River at Van Meter, a 8900-km^2 catchment located in central-western Iowa. Statistical model fits for each discharge quantile (from seasonal minimum to maximum; predictands) are based on observed basin-averaged total seasonal precipitation and annual row crop (corn and soybean) production acreage (predictors).

Figure 1 summarizes the skill of the average of the eight NMME models used in predicting seasonal precipitation over this basin for different lead times. Overall, there is limited skill, in particular for the fall and winter. The skill is generally better at the shorter lead times and in the summer.

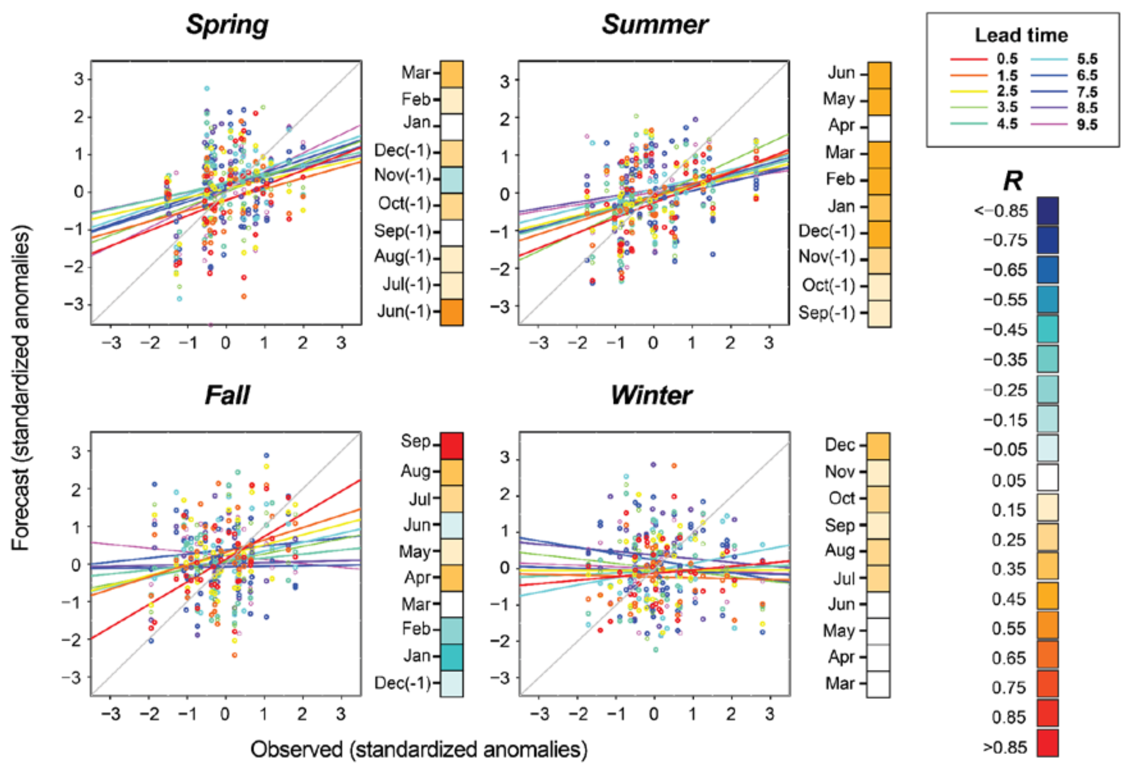

Figure 1. Scatterplots of observed basin-averaged precipitation for the Raccoon River watershed, versus NMME precipitation (ensemble mean) at different lead times. Different lead times of the NMME forecasts are shown using a color spectrum. The correlation coefficient (R) between observed and forecast seasonal standardized anomalies is shown for just the period 2001-2015. Adapted from Slater et al. (2016b).

Given the potentially limited skill in predicting precipitation over this basin, one of the research questions we want to address is whether we can still extract potentially useful information for seasonal streamflow predictions.

Using the most recently-updated relationship between predictand and predictors every year, we produce forecasts from one to ten months ahead of the given season based on annual row crop acreage from the previous year (persistence forecast) and the monthly precipitation forecasts provided by dynamical predictions from the eight GCMs from NMME. Additionally, observed precipitation from the month preceding each season is used to characterize antecedent soil moisture conditions.

The results in Figure 2 highlight the skill of our seasonal discharge prediction models for different discharge quantiles (i.e., low flow, median flow and high flow) and three different lead times (i.e., 1-, 6- and 10-month lead times). Overall, these simple models are able to capture well the year-to-year variations in discharge, from low to high flows. They work the best for the spring and summer, with a general better performance at the shortest lead times.

The skill values for all the lead times, quantiles and seasons are summarized in Figure 3. While overall we perform the best at the shortest lead time, the skill exhibited by these models tends to persist for several months. We generally get high correlation coefficients in the high flows in the spring, and from low to high flows in the summer. In the fall, the skill is high at the shorter as well as longer lead times. In the winter, on the other hand, the overall skill is lower. In addition to the correlation coefficient, we also considered the mean absolute scaled error (MASE; Hyndman and Koehler 2006, Franses, 2016). The MASE score, a scaled error measure, is used to compare the forecast against the average one-step naïve forecast, where values smaller than 1 indicate that the model performs better, on average, than the one-step naïve forecast. Although the September initialization for the fall still performs well in terms of MASE, the best scores are obtained in the spring and summer months (low values, in red; Figure 3), which correspond to the best precipitation input forecasts (Figure 1) and also produce the most variable flow forecasts (Figure 2). In fact, with the exception of fall, the high flows tend to be as well or better predicted than the other flow quantiles. These results show that we can provide skillful predictions of seasonal discharge with a lead time of several months.

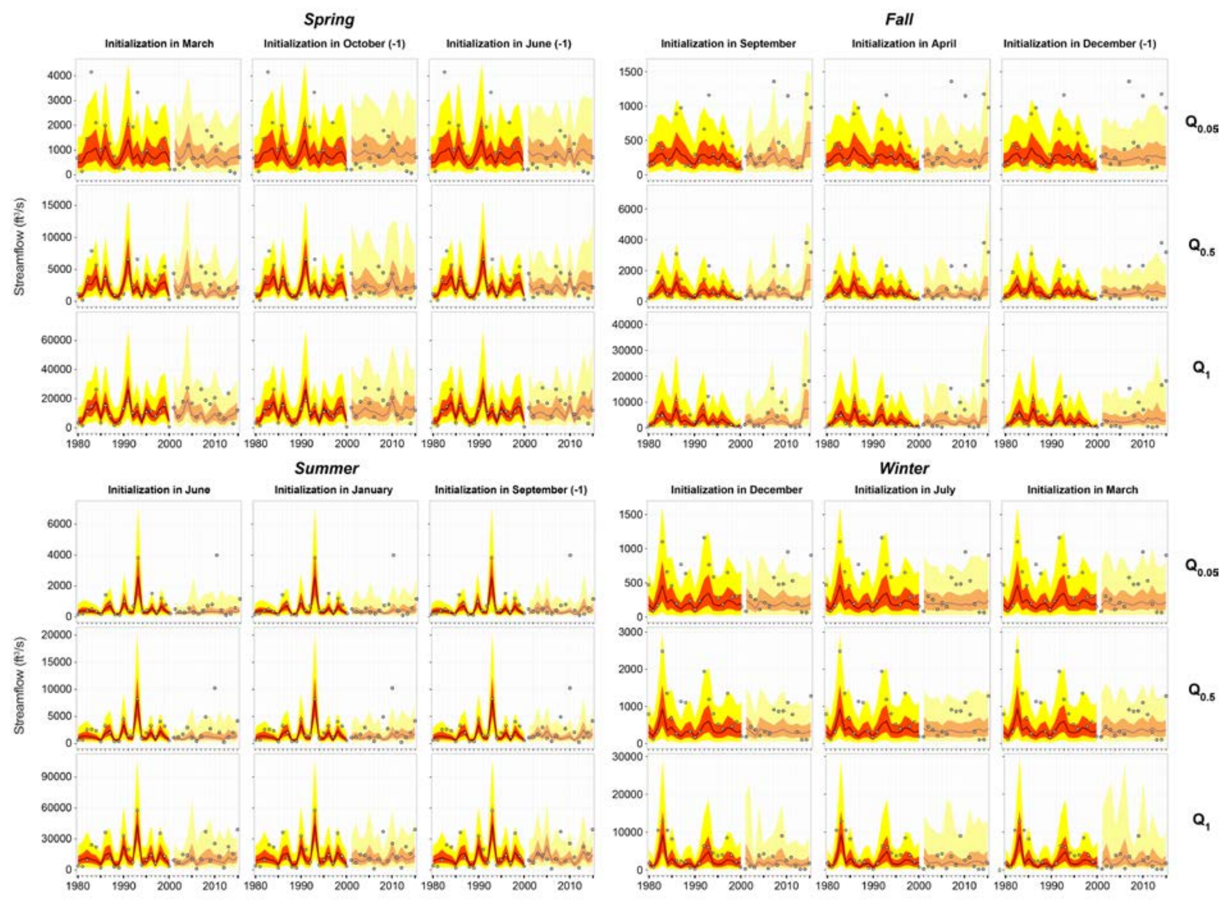

Figure 2. Time series showing the model fit (1980-2000) and forecast (2001-2015) against the observed values. For every season, and three different initialization times (1, 6 and 10 months ahead of the season), five quantiles of the predicted discharge distribution are shown ($Q_{0.05}$, $Q_{0.25}$, $Q_{0.50}$, $Q_{0.75}$ and $Q_{0.95}$) for three quantiles (rows): low flow ($Q_{0.05}$), median flow ($Q_{0.50}$), and maximum seasonal flow (Q_1). Adapted from Slater et al. (2016b).

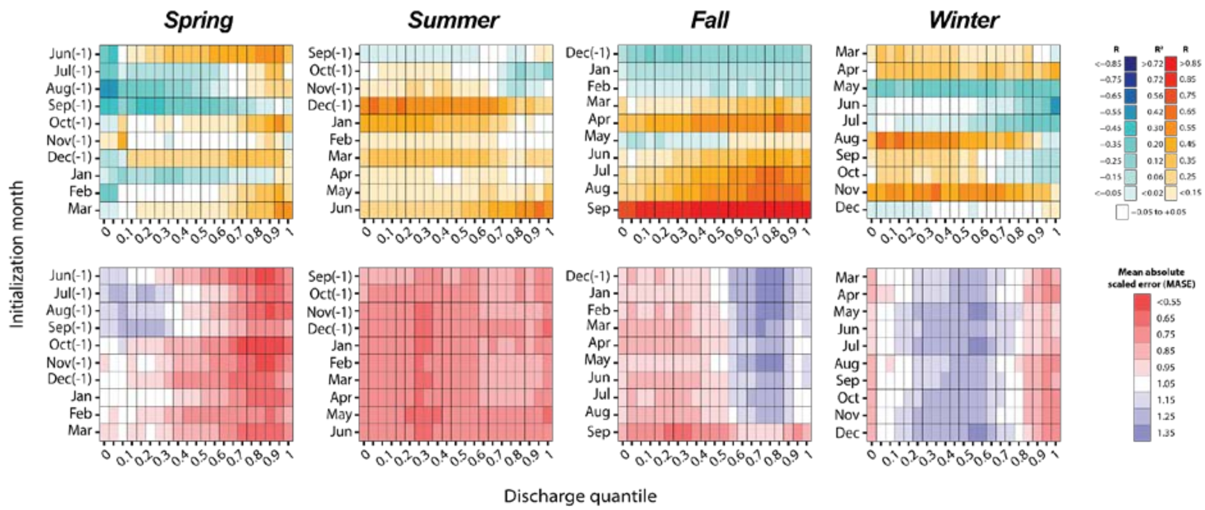

Figure 3. Evaluation (2001-2015) in terms of correlation coefficient/coefficient of determination (R/R^2) and MASE. Skill is shown for all discharge quantiles (x-axis) and initialization months (lead time ahead of each season; y-axis), for all four seasons (columns). Red colors indicate positive skill (strong R/R^2 and low MASE). Adapted from Slater et al. (2016b).

We have also generated the forecast for 2016 (Figure 4). Our flow forecasts are based on all of the available precipitation forecasts, for all available lead times available at the time of the writing of the manuscript. Results for winter 2016 (i.e., December 2015 through February 2016) indicate slightly below-average predicted flow distributions for $Q_{0.05}$ and $Q_{0.5}$ (i.e., the median of the predicted distribution is below the observed seasonal average for 2001-2015) with maximum flows (Q_1) very slightly above average (Figure 4). The spring months are roughly on par with the historical average (although low-flows will be slightly higher than normal), with summer months slightly below average. Towards the end of the year, the forecasts predict discharge to fall well below the historical climatology, although data are only available for two lead times by that point. Overall, it seems that rivers should be below or close to the 2001-2015 average conditions across the Raccoon River basin.

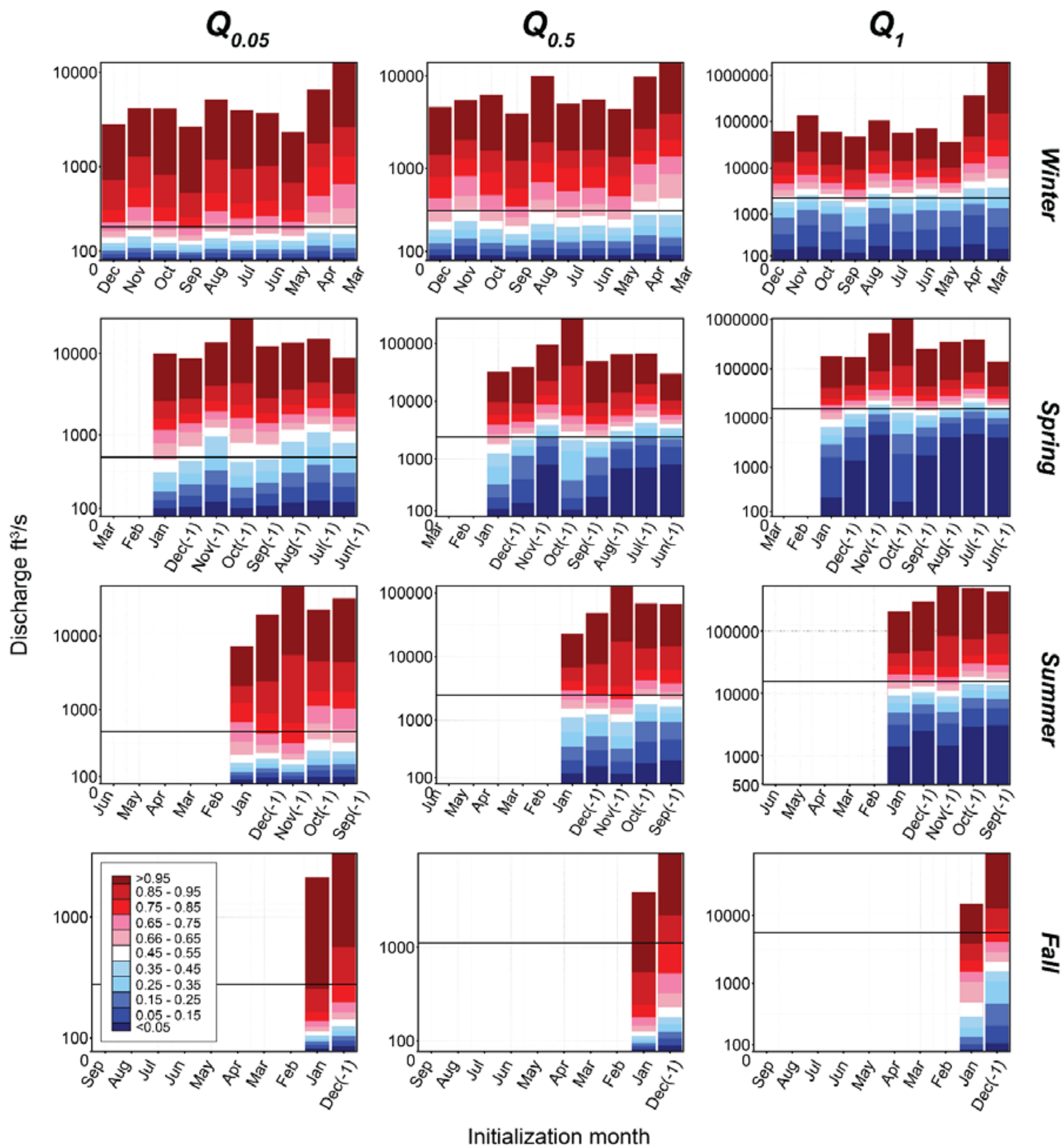

Figure 4. Seasonal forecast for the Raccoon River in 2016, issued in January 2016. The x-axes indicate the initialization month of the seasonal forecast, ranging from the shortest lead time (left) to the longest lead time (right). For example, complete forecasts for the fall season (September, October, November), are issued in December of the previous year, or January. The y-axes indicate discharge quantiles from the forecast flow distribution, shown with a color gradient ranging from low (blue shades) to large (red shades) quantiles. The quantiles around the median forecast flow ($Q_{0.45}$-$Q_{0.55}$) are shown in white. Darker shades indicate the extremes of the flow frequency distribution predictions. The horizontal black line on each sub-panel indicates the seasonal average flow for the period 2001-2015.Adapted from Slater et al. (2016b).

References

Franses, P.H., A note on the Mean Absolute Scaled Error, *International Journal of Forecasting*, 32(1), 20–22, 2016.

Hyndman, R.J., and A.B. Koehler, Another look at measures of forecast accuracy. International Journal of Forecasting, 22(4), 679–688, 2006.

Kirtman, B.P., and Coauthors, The North American multimodel ensemble: Phase-1 seasonal-to-interannual prediction; phase-2 toward developing intraseasonal prediction, *Bulletin of the American Meteorological Society*, 95(April), 585–601, 2014.

Slater, L.J., G. Villarini, and A.A. Bradley, Evaluation of the skill of North-American Multi-Model Ensemble (NMME) global climate models in predicting average and extreme precipitation and temperature over the continental USA, submitted to *Climate Dynamics*, 2016a.

Slater, L.J., G. Villarini, A.A. Bradley, and G.A. Vecchi, A statistical/dynamical framework for seasonal streamflow forecasting in an agricultural watershed, submitted to *Climate Dynamics*, 2016b.

Villarini, G., and A. Strong, Roles of climate and agricultural practices in discharge changes in an agricultural watershed in Iowa, *Agriculture, Ecosystems and Environment*, 188, 204-211, 2014.

Awards resulting from work on this project

- Source of Support: U.S. Army Corps of Engineers
  Lead PI. Title: Water Resources and Geospatial Analysis: Attribution of Changes and Evaluation of Actionable Climate Information across the Northern Great Plains and the Central United States
  Award: $468,264 [12/28/2015 – 12/31/2018]

- Source of Support: National Oceanic and Atmospheric Administration
  Lead PI. Title: NMME Precipitation and Temperature Forecasts for the Continental United States and Europe: Diagnostic Evaluation and Development of Multi Model Applications
  Award: $69,999 [08/01/2015 – 07/31/2016]

Student support

- Shi, Anda (Undergrad)
- Slater, Louise (Post-doc)
- Khouakhi, Abdou (Post-doc)

Outcomes over the period March 1, 2015- Feb 29, 2016

<u>Manuscript:</u>

- Slater, L.J., G. Villarini, and A.A. Bradley, Evaluation of the skill of North-American Multi-Model Ensemble (NMME) global climate models in predicting average and extreme precipitation and temperature over the continental USA, submitted to *Climate Dynamics*, 2016.
- Slater, L.J., G. Villarini, A.A. Bradley, and G.A. Vecchi, A statistical/dynamical framework for seasonal streamflow forecasting in an agricultural watershed, submitted to *Climate Dynamics*, 2016.

<u>Abstracts to conferences:</u>

- Slater, L., G. Villarini, A. Bradley, and G.A. Vecchi, Seasonal forecasting of discharge for the Raccoon River, Iowa, *General Assembly, EGU*, Vienna, Austria, April 17-22, 2016.
- Villarini, G., L. Slater, and K. Salvi, Discharge forecasting for the Raccoon River at Van Meter, Iowa: From next season to the next decade, *Environmental and Water Resources Conference*, Ames, Iowa, April 7, 2016.

- Villarini, G., and L. Slater, Seasonal forecasting of discharge for the Raccoon River at Van Meter, Iowa, *Iowa Water Conference,* Ames, Iowa, March 24, 2016.
- Slater, L., G. Villarini, and A. Bradley, Diagnosis of North American Multi-Model Ensemble (NMME) skill for predicting floods and droughts over the continental USA, *AGU Fall Meeting*, San Francisco, California, December 14-18, 2015.

Development of a Comprehensive Hazard to Loss Modeling Methodology for the Residential Damage Associated with Inland Flooding from North Atlantic Tropical Cyclones

Basic Information

Title:	Development of a Comprehensive Hazard to Loss Modeling Methodology for the Residential Damage Associated with Inland Flooding from North Atlantic Tropical Cyclones
Project Number:	2014IA257G
USGS Grant Number:	G14AS00014
Start Date:	9/1/2014
End Date:	8/31/2016
Funding Source:	104G
Congressional District:	IA002
Research Category:	Climate and Hydrologic Processes
Focus Category:	Floods, Economics, Climatological Processes
Descriptors:	None
Principal Investigators:	Gabriele Villarini, Jeffery Czajkowski, Erwann MichelKerjan

Publication

1. Managing and Financing Extreme Events Project 2015 Annual Meeting, Wharton Risk Management and Decision Processes Center, Philadelphia, PA (October, 2015)

Problem and Research Objectives

We propose to develop statistical models to describe the relation between inland flooding associated with North Atlantic tropical cyclones (TCs) and impacts (claims and losses) in the United States. This is a topic of high socio-economic relevance, but regretfully has received very little attention as most U.S. TC loss assessment efforts are focused on coastal areas. Its importance has unfortunately been highlighted in the recent past, with significant inland flooding associated with Hurricanes Irene (2011) and Isaac (2012). These hurricanes, however, are not isolated cases, but are representative of much larger set of events with large impacts (e.g., Pielke and Klein 2005; Pielke et al. 2008; Changnon 2008; Jonkman et al. 2009; Czajkowski et al. 2011, 2013; Mendelsohn et al. 2012; Peduzzi et al. 2012; Rappaport 2014).

The main outcomes of the proposed research are: 1) at a fairly granular level the identification of the areas that are more at risk from inland flooding from North Atlantic TCs; 2) the characterization of the extent and magnitude of these events; 3) the development of statistical models relating flood magnitude to direct economic losses importantly controlling for the associated exposure and vulnerability aspects over the period 2001-2012; 4) the use of the resulting empirical relationships to perform sensitivity analysis examining the potential impacts of pre-2000 TCs under the current level of exposure and vulnerability. The proposed work will provide information instrumental for the assessment and understanding of the changes in TC flood hazard (both in terms of spatial location and magnitude) over the 20th century, together with a quantification of the associated impacts.

Methodology

The goal of our work is to develop a data-driven climatology of inland flooding associated with North Atlantic TCs and to model the associated impacts in the United States. Significantly, we utilize a data-driven approach to flood hazard characterization based on discharge observations from a dense network of stream gaging stations, leveraging the wealth of discharge data collected and disseminated by the U.S. Geological Survey (USGS). Moreover, we have a unique access to the federally-run National Flood Insurance Program (NFIP) data - flooding in the United States is mainly insured by this public program - to allow for examination of flood claims, damage and relevant exposure data. The focus of our work is on the area of the continental United States east of the Rocky Mountains.

The analysis of flooding associated with TCs at the regional scale requires accounting for the dependence of discharge on drainage area. Here we follow the approach described in Villarini et al. (2014a) and normalize the peaks caused by TCs by the at-site 2-year flood peak. The selection of the 2-year return period is due to two main reasons: 1) it is roughly the discharge value corresponding to bankfull conditions, with values larger than it pointing to out-of-bank flow; 2) it can be estimated reasonably accurately from the data using a relatively small window. One of the issues with the flood ratio is that it does not generally provide information regarding the severity of the flood event. To address this issue and similar to Villarini et al. (2014a), we will use the flood status classification by the National Weather Service (NWS), and consider four categories in the analysis (see next section for results related to this issue). We define as flooding associated with a TC the largest flood peak measured by a station located within 500 km from the center of the storm during a time window of two days prior and seven days after the passage of the storm (e.g., Villarini et al. 2014a).

The four basic components of natural hazard risk assessment are: hazard, exposure, vulnerability and loss. In modeling the number of flood claims incurred (predictand), we develop statistical models in which the response variable is related to different predictors. For each impacted area of the storm, the covariates we are currently considering (amongst others) include the above-defined flood ratio and its NWS classification, the number of housing units, the total population, the number of flood insurance policies-in-force, event-specific storm fixed effects, geographic-specific impacted area fixed effects, and areas of high flood risk as designated by a 1996 Natural Disaster Study conducted by the Federal Emergency Management Agency on behalf of the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (https://www.npms.phmsa.dot.gov/DisasterData.aspx). These models will represent losses and insurance claims for 28 North Atlantic TCs for the 2001-2014 period.

Principal Findings and Significance

Over the past year, we have made significant progress to address the proposed research questions. We have systematically assessed freshwater flood risk through an interdisciplinary approach that analyzes the full set of all 28 significant U.S. landfalling TC related flood events (https://www.fema.gov/significant-flood-events) having occurred from 2001 to 2014. We have mapped and modeled the relationship among hazards, exposure and economic impacts focusing on residential losses. From a hazard perspective, we have leveraged daily discharge data from 3,035 U.S. Geological Survey (USGS) stream gages. To enable a detailed examination of associated losses, we have accessed data from the federally-managed National Flood Insurance Program (NFIP) and catalog 443,484 residential freshwater flood insurance claims associated with these 28 TCs. While flood insurance markets vary across countries, residential flood insurance in the U.S. is mainly provided under this public program.

We show that, on average, each TC affected nearly 8,000 communities across the country. Communities do vary markedly by land size and population, but on average this translates into over 40 million total housing units and 93 million people along the entire TC path. Across the 28 TCs we find that about one third of the total residential flood insurance claims were related to storm surge, with the remaining two thirds thus being freshwater driven–and these being equally located between coastal communities and inland areas. While this confirms coastal flooding risk we also demonstrate the significant spatial extent of TC freshwater flooding for inland communities.

The number of claims from the NFIP serves as the basis for our statistical modeling to identify the major drivers associated with freshwater flood losses. We then use our derived statistical relationships to understand future flood risk given potential increases in flood hazard due to a warmer climate and expanding urbanization. We find that there could be up to a 17% increase in residential loss (again, using the number of NFIP insurance claims as a proxy) for a 20% increase in flood magnitude, and a 2.4% increase due to changes in impervious surface of the same magnitude as what experienced over the first decade of the 21st century. Since losses from major TCs can be in billions of dollars, this constitutes a significant exposure increase for the communities at risk. Thus our findings provide the details to comprehensively assess TC freshwater flood risk now and under plausible changing conditions both in terms of flooding and urbanization. In a world of increasing natural disaster risk, this view represents an important move toward greater natural disaster resilience.

TC Freshwater Flood Risk in U.S. Communities

The US Federal Emergency Management Agency (FEMA) defines a community as a political entity (e.g., city, town, county) having floodplain ordinance authority (FEMA 2002), thus a community serves as our primary unit of analysis here. Across all 28 TCs a total of 218,146 communities were affected in 38 of the 50 U.S. states. On average 7,791 communities were affected per event, with Ike (2008) affecting the most (16,060 communities) and Wilma (2005) the least (617 communities). The maximum number of times an individual community was affected was 21, or by 75% of the TC events considered here, with affected communities extending well inland. Although we find that the vast majority of these affected communities (90%) experience a TC freshwater flood hazard below flood stage level, this expansive geographic extent of the flood hazard begins to highlight the broad scope of potential risk.

The 28 TCs in this study have indeed been responsible for flooding and major flooding over large areas of the central and eastern U.S. affecting a total of 21,705 communities, or approximately 775 communities on average per event (Figure 1). As expected, the Gulf Coast and the U.S. eastern seaboard (and Florida in particular) are the areas that have been affected the most by TC flooding, representing 55% of the total 21,705 communities affected by both flooding and major flooding over the period 2000-2014. However, the extent of freshwater flood hazard is not limited to these coastal areas, with the remaining 45% of the communities affected by flood and major flood effects over that same period being in inland, i.e., non-coastal, states. And while nine costal states - Florida, Texas, Louisiana, New Jersey, South Carolina, New York, North Carolina, Virginia, and Georgia - represent nearly 75% of the total 5.6 million flood insurance policies covered by the NFIP (Michel-Kerjan and Kousky 2010), we still found that about 200,000 policies on average per event are in-force in inland states, a non-trivial amount at risk. Lastly, and as was found with Hurricane Ivan (Czajkowski et al., 2013), freshwater flood TC effects are not limited to communities that participate in FEMA's flood program, highlighting flood hazards (Figure 1) that occur in areas with no corresponding flood insurance protection in place, and thus likely with limited overall floodplain management.

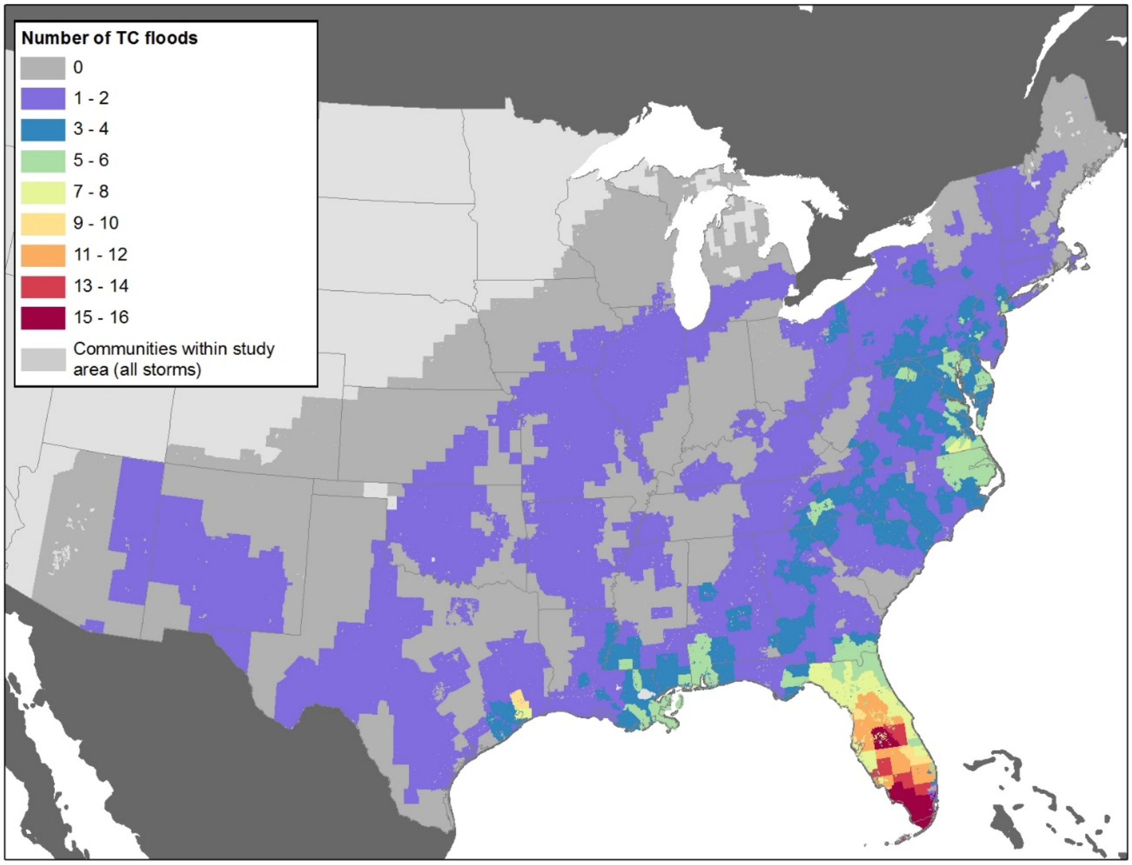

Figure 1. Flooding associated with TCs. This map shows the number of flood events (flood ratios larger than 1) in each of the FEMA defined communities that have been within 500 km of the passage of any of the 28 significant flood event TCs considered in this study (2000-2014).

Using Flood Insurance Claims as a Loss Proxy

A comprehensive view of TC freshwater flood risk is the combination of both flood hazard and its associated impact. Our impact data are derived from the NFIP claim portfolio and thus only encompass governmentally insured residential losses. Consequently, the data should be considered a lower bound estimate of the total freshwater flood impacts experienced in all flood hazard affected areas shown in Figure 1. Nonetheless, this federal insurance program is, as mentioned earlier, the primary residential insurer of flood risk in the U.S. and we draw upon an extensive claim database with over 2 million records. In terms of the freshwater flood impacts from these 28 TC events we catalog a total of 443,484 residential freshwater flood insurance claims incurred, or an average of 15,839 per event. While we focus on the number of claims incurred, we can take the $34,000 mean claim values from a recent study that analyzes 35 years of operation of that federal program (Kousky and Michel-Kerjan, 2016) to estimate corresponding average residential damage amounts from these incurred claims at over $530 million per TC event.

Figure 2 (left panel) illustrates the location of all the communities with freshwater flood claims and Figure 2 (right panel) shows the numbers of times communities have experienced a major TC flood. As expected, the locations of TC flood hazards and the majority of flood insurance in-force cause claims to be highly concentrated in coastal communities. But again, freshwater flood losses are not limited to these areas with significant claim amounts in inland areas of the U.S., including Pennsylvania, West Virginia, Ohio, Illinois, and Missouri. Finally, FEMA designates special flood hazard areas (SFHA) as being high-risk. Still, we find that 26% of the total 443,484 claims incurred by the 28 TC freshwater flooding events we studied were actually outside of those areas, where the risk is advertised to residents by the federal government as being low.

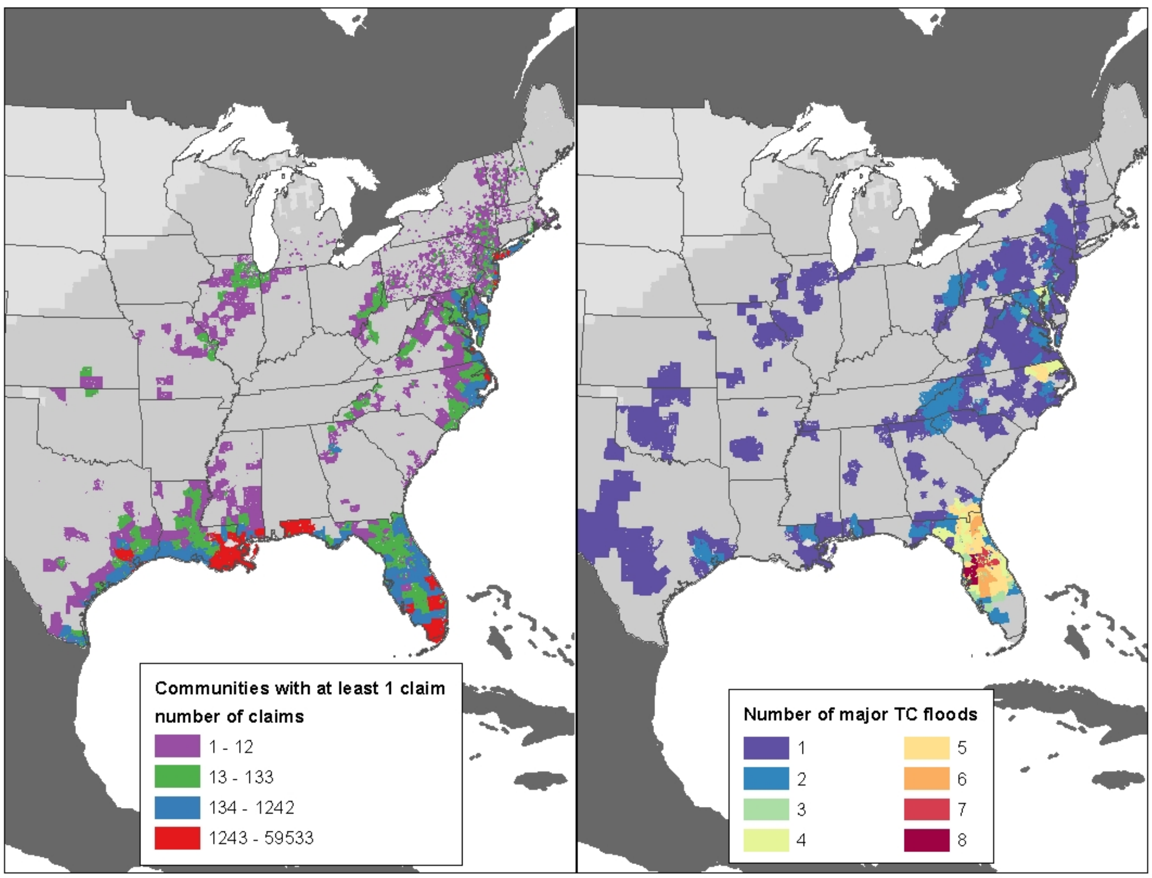

Figure 2. Communities with at least 1 residential claim (left panel) and communities impacted by at least one major TC flood over the period 2000-2014 (right panel).

Modeling Freshwater Flood Impacts

Currently, the National Weather Service (NWS) only stipulates that areas under a flood hazard are at simply an increased threat to property, something we would like to better quantify for risk assessment. Thus, we move to the statistical modeling of the number of NFIP insurance claims incurred at each NFIP community in terms of the key drivers of this impact reflecting not only the flood hazard, but also relevant exposure and vulnerability components of that. The freshwater flood hazard component is represented by the TC discharge values normalized by the at-site two-year flood event, and categorized as bankfull, minor, moderate and major flooding (we refer to this as the flood ratio). To quantify exposure and vulnerability, we use variables related to the community's distance from the coastline, whether it is located within a coastal state, its percentage of impervious surface (to examine the effects of urbanization and based upon 2006 values), the proportion of the community in low, medium or high risk areas, the number of housing units (based on the 2010 values), and the number of FEMA residential flood insurance policies-in-force in the community per year of the event. For statistical power purposes we pool the data from all the 28 TCs; but as these are different types of TC flooding events we also control for any unobserved event-specific fixed effects through event dummy variables represented by the TC intensity at landfall. We also include year variables to control for any unobserved time-specific fixed effects.

Table 1 presents the results from our empirical analysis where we model the count of claims for all 150,546 communities with at least one residential insurance policy-in-force, and further utilize a zero-inflated negative binomial regression (ZINB) model with robust standard errors to account for the large number of these communities with zero claims incurred. The Wald test of the joint insignificance of our explanatory variables is rejected at the 1% level, with 20 of the 24 individual predictors in the model significant at the 10% level or less, including notably the flood hazard variables at the 1% level. Based on our modeling results (Table 1), flood conditions lead to an increase in the number of insurance claims, when compared to bankfull conditions. We find a non-linear marginal increase for higher flood magnitude when compared to the bankfull conditions: the expected number of claims increases by a factor of 2.5 for minor flooding, 4.9 for moderate, and 12.1 for major flooding. The impact of flood hazard risk is also further quantified by examining the inherent proportion of each community in low-, medium- or high-risk areas as designated by a 1996 Natural Disaster Study conducted by the FEMA on behalf of the U.S.

Department of Transportation Pipeline and Hazardous Materials Safety Administration (see Methods section for further overview). For each community we calculated the proportion of area representing three levels of low, medium, and high flood risk. These results indicate that there is a larger number of claims in those communities that have a higher proportion of high flood risk as would be expected

The number of insurance claims resulting from a tropical storm compared to a Cat 1-2 hurricane are smaller by a factor 0.1, while the claims associated with major hurricanes (Cat 3-5) increase by a factor of 9.9 on average. A possible explanation for these results is tied to the larger size and rainfall amounts in hurricanes compared to tropical depressions and storms (Jiang et al., 2008), potentially leading to saturated ground and higher flood magnitudes.

Whether the community is located along the coast or further away from it also plays a role where we estimate a reduction in insurance claims by a factor of 0.6, 0.6, and 0.2 for communities located in distance bands 25 to 100 miles, 100 to 500 miles, and greater than 500 miles from the coast, respectively. Finally, we also find that there is a 100% increase in the average number of expected insurance claims per community for a 1% increase in impervious surface. From a hydrologic standpoint, we expect larger flood peaks in urban rather than rural settings because of the limited infiltration, leading to faster response and larger peaks. These results indicate that urbanization and conversion of the landscape towards impervious surface has played a significant role in increasing the impacts of TC flooding. As expected, the count of claims increases as the number residential policies in-force increases, but decreases as housing units increase. This accounts for relatively low market penetration rates, especially outside of the FEMA-defined high risk special flood hazard areas (SFHAs). Finally, the two zero-claim probability explanatory variables in the inflate portion of the model (maximum flood peak ratio observed and the log of residential policies in force) have the expected sign (i.e., higher values of each lead to lower probability of observing 0 claims incurred) and are statistically significant at less than the 1% level.

	Estimate	Robust Standard Error	[95% Confidence Intervals]
Minor flooding	0.921***	0.104	[0.718; 1.125]
Moderate flooding	1.579***	0.120	[1.344; 1.814]
Major flooding	2.493***	0.124	[2.250; 2.736]
LnResPol	0.896***	0.044	[0.809; 0.983]
LnHousing	-0.148***	0.042	[-0.231; -0.066]
PropLowRisk	-0.183	0.336	[-0.842; 0.476]
PropMedRisk	0.090	0.340	[-0.576; 0.756]
PropHighRisk	0.623*	0.330	[-0.024; 1.269]
YrDummy2002	-1.079***	0.213	[-1.496; -0.662]
YrDummy2003	-0.329	0.371	[-1.056; 0.398]
YrDummy2004	-4.058***	0.212	[-4.473; -3.643]
YrDummy2005	-3.304***	0.212	[-3.739; -2.870]
YrDummy2006	-2.884***	0.321	[-3.512; -2.260]
YrDummy2007	-2.475***	0.283	[-3.031; -1.920]
YrDummy2008	-1.446***	0.170	[-1.779; -1.113]
YrDummy2011	-1.333***	0.192	[-1.709; -0.958]
YrDummy2012	-0.464**	0.194	[-0.844; -0.085]
TS	-2.400***	0.148	[-2.689; -2.110]
MajorHurr	2.298***	0.113	[2.077; 2.518]
CoastalState	0.029	0.081	[-0.129; 0.187]
Impervious	0.700***	0.182	[0.344; 1.055]
Miles25-100	-0.561***	0.095	[-0.748; -0.375]
Miles100-500	-0.593***	0.103	[-0.796; -0.390]
Miles500+	-1.422***	0.367	[-2.146; -0.697]
Intercept	-1.248***	0.398	[-2.028; -0.468]

Inflate	Estimate	Robust Standard Error	[95% Confidence Intervals]
MaxFR	-1.436***	0.032	[-1.498; -1.373]
LnResPol	-0.120***	0.010	[-0.139; -0.010]
Intercept	2.427***	0.063	[2.303; 2.549]

	Estimate	Robust Standard Error	[95% Confidence Intervals]
Ln(Dispersion α)	1.517***	0.041	[-1.437; -1.596]
Dispersion α	4.555***	0.185	[4.207; 4.932]

Table 1. Statistical modeling of the number of freshwater related residential flood insurance claims using a zero-inflated negative binomial model. There are 150,546 total observations, of which 6,631 are non-zero. The predictors are a community's distance from the coastline ("Miles25-100", "Miles100-500", "Miles500+"), whether it is located within a coastal state ("CoastalState"), its percentage of impervious surface (based upon 2006 values; "Impervious"), the proportion of the NFIP community in low, medium or high risk areas ("PropLowRisk", "PropMedRisk", "PropHighRisk"), the natural log number of housing units (based on the 2010 values; "LnHousing"), and the natural log of the number of NFIP residential policies-in-force in the community per year of the event ("LnResPol"). The flood ratio is transformed into a dummy variable, with bins of a flood ratio below 1 is for bankfull conditions; a flood ratio between 1 and 1.5 represents minor flooding conditions, while values between 1.5 and 2.2 and larger than 2.2 are indicative of moderate and major flooding, respectively, where bankfull is the omitted dummy variable category. We also control for any unobserved event-specific fixed effects through event dummy variables represented by the TC intensity at landfall – tropical storm, hurricane, and major hurricane with hurricane the omitted category ("TS", "MajorHurr"). We also include year variables to control for any unobserved time-specific fixed effects with 2001 the omitted category ("YrDummy"). The zero-inflated part of the model uses as predictors the largest flood ratio for a given community ("MaxFR") and the natural log of the number of NFIP residential policies-in-force in the community per year of the event ("LnResPol"). The results for the coefficient of dispersion α are also reported, highlighting that the data are overdispersed (α larger than 0). The symbols "***", "**", "*" refer to coefficients that are different from zero at the 0.01, 0.05, and 0.10 significance level, respectively.

We validate our regression results in two main ways: 1) in Figure 3 using the results from Table 1 (including the confidence intervals on our estimated coefficients) we compare the fit of predicted vs. actual flood claims per each of the 28 TCs; and 2) we apply a k-fold cross validation on the model in Table 1 to evaluate its ability to fit out-of-sample. Figure 3 shows that for 17 of the 28 TC events the actual number of claims incurred falls within the 95% confidence bound of predicted counts estimated from our model, providing further validity to our estimated model. The pseudo-R-squared statistics generated from k-fold cross validation indicate that the ZINB models consistently capture about 12% of the variation in out-of-sample test data, with a high value of 52%. The cross-validation goodness-of-fit results are lower than the full model results with pseudo r-squared values here closer to 30%. Importantly though, in all k-fold estimation, the key FPR variables of interest perform as they did in Table 1 in terms of magnitude, sign, and statistical significance, which provide further validation of our findings.

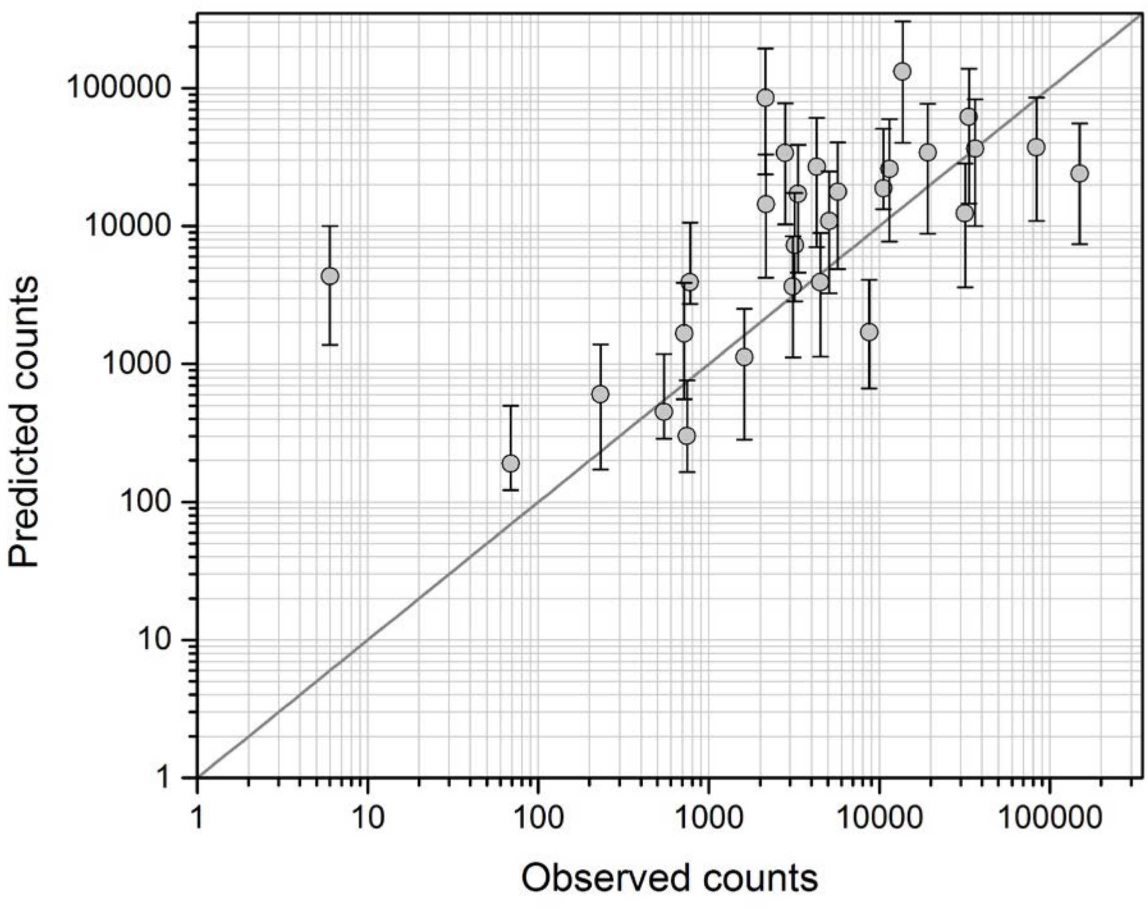

Figure 3. Fit of Predicted vs. Actual Claims Incurred per TC. Log scales of actual and predicted claims are taken and 95% confidence intervals on the Table 1 estimated coefficients are shown for predicted counts. Each observation represents one of the 28 TCs.

Future Changes in TC Freshwater Flood Losses

These results have unveiled and further quantified some of the major drivers responsible for the observed residential freshwater flood loss from U.S. landfalling TCs including the flood hazard magnitude and the level of urbanization (impervious surface coverage). Different modeling studies point to an increase in U.S. TC rainfall up to ~20% in a warmer climate (Knutson et al. 2010, 2013, Scoccimarro et al. 2014, Villarini et al. 2014b). Moreover, large areas of the continental U.S. that are under threat from TC strikes have also experienced increasing urbanization.

Significantly our methodology allows us to predict via a comparative statics analysis how changes in the climate system and urbanization might impact residential loss, assuming that all the other exposure and vulnerability factors stay the same. As an illustration, we select two recent TC events, Ike (2008) and Irene (2011), and determine what the local and regional residential economic impacts of those two disasters would likely be if flood magnitudes were increased up to 20% under the present level of exposure and vulnerability. Similarly, we measure what the effects would be if urbanized areas increased under the present level of flood hazard. We examine these two hurricanes as representative of high impact storms affecting the eastern and central U.S.

Figure 4 illustrates that by increasing the observed Hurricanes Ike and Irene TC flood ratios by 1%, 5%, 10%, and 20% at every USGS stream gage location, we obtain increased predicted loss amounts of 0.7%, 3.5%, 8.6%, and 17.1%, respectively (measured by expected flood insurance claims). These increases are compared to predictions of greater urbanization from increases in impervious surfaces based on the 2001 to 2011 percentage increases, and assuming this rate of change to persist to 2021. Predicted claims increase by 2.4% with the increased urbanized land-use. In other words, increasing urbanization and its continued recent pace is equivalent to a 3% increase in TC rainfall.

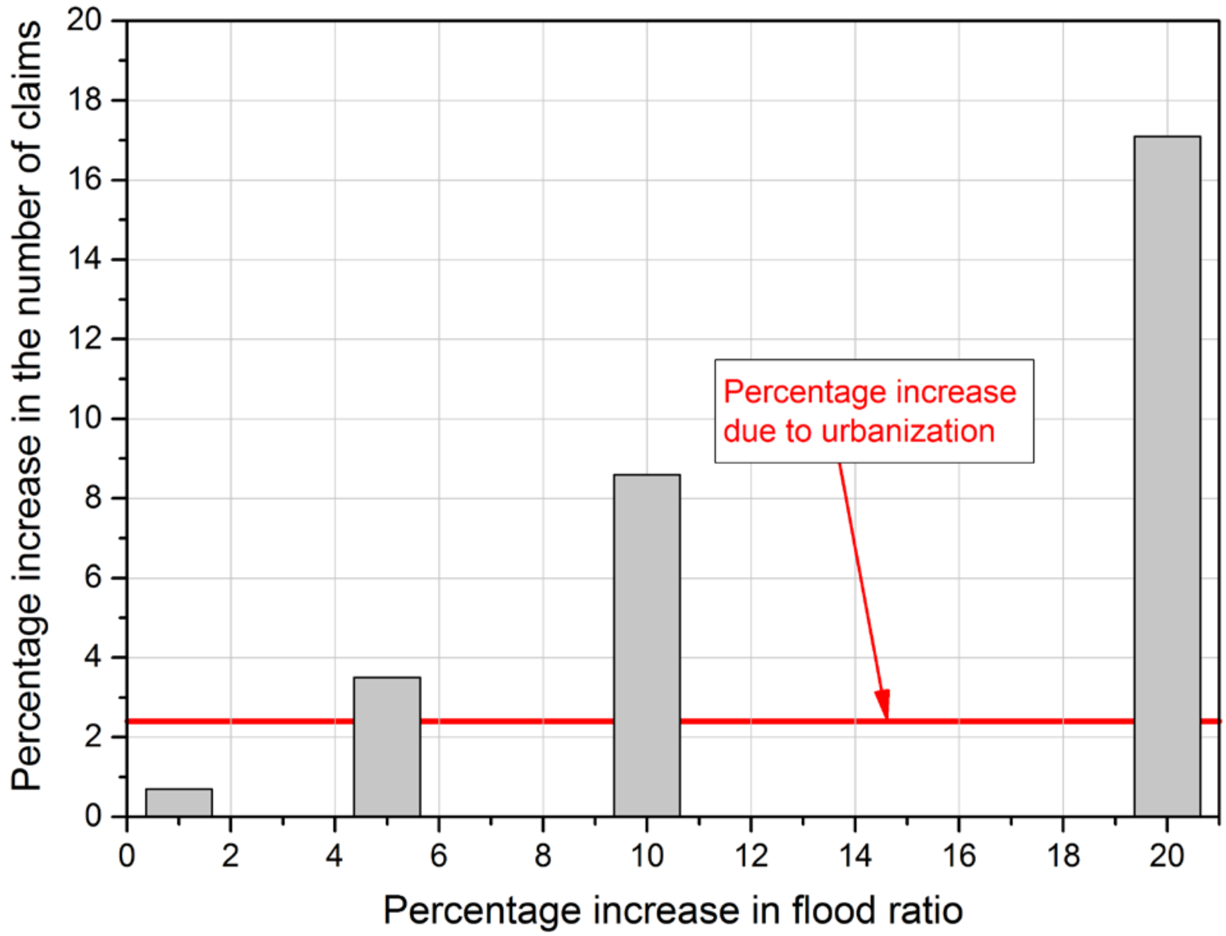

Figure 4. Increased Flood Claims resulting from increased TC flooding and increased urbanization

This novel study characterizes U.S. communities that have been at large risk of freshwater flooding from all substantial TCs between 2000 and 2014. We show that the number of residential losses from that type of flooding were actually twice as high compared to storm surge losses (using the number of residential flood insurance claims of the U.S. federal flood insurance program as a proxy). Furthermore, freshwater flood impacted areas from coastal versus inland freshwater flooding were divided 55/45. We are also able to determine the relationships between intensity of the TC flood event (measured by flood peak ratio) and losses, under current and future conditions. Thus our results can provide a new way to undertake flood risk assessment across all areas potentially impacted by TCs, not just coastal landfall locations.

This work has important implications in the U.S., and internationally. As indicated, media attention has typically focused on TCs at landfall given that this is when the impacts are most visual and concentrated. But our findings shed new light on the total losses triggered by those

TCs, along their entire path inland. In a recent report (US Department of Commerce, 2012) , the U.S. National Weather Services (under NOAA) which provides the official TC alert for the nation, states that improvement in how it communicates and educates on the risk of inland flooding was the number one overreaching recommendation. FEMA has also recently been tasked with remapping areas across the country for flood risk and additionally a number of U.S. inland flood catastrophe models are in development, and we think this analysis should also be of use in both of these endeavors. Finally, while we focus on the U.S., flood remains the number one natural hazard in a number of countries around the world. We hope future work inspired by our proposed approach conducted at a national level over all significant flood events can be carried out there as well by the research community, governments, insurers and emergency managers, all having a deep interest in improving accuracy of flood risk so as to limit human and economic loss from future flood catastrophes.

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Student support

- Aryal, Yog Nath (Ph.D. student)
- Jeffrey Czajkowski (Post-doc)
- Marilyn Montgomery (Post-doc)

Outcomes since the beginning of the project

Manuscripts:

- Czajkowski, J., G. Villarini, M. Montgomery, E. Michel-Kerjan, and R. Goska, Assessing freshwater flood risk from North Atlantic tropical cyclones, under review (2016).

Presentations:

- Managing and Financing Extreme Events Project 2015 Annual Meeting, Wharton Risk Management and Decision Processes Center, Philadelphia, PA (October, 2015)

Information Transfer Program Introduction

Program Coordinator Melissa Miller began her fourth year at the Center, allowing for continued growth in the Information Transfer program.

Information Transfer 2015

Basic Information

Title:	Information Transfer 2015
Project Number:	2015IA261B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	IA-004
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Richard Cruse, Melissa S Miller

Publications

There are no publications.

2015-2016 Iowa Water Center Information Transfer Project

The Iowa Water Center (IWC) places great importance on the Information Transfer aspect of its 104(b) program. Information Transfer activities achieve multiple goals for IWC: inform consumers about water related issues and research; connect researchers to complementing projects and facilitate collaboration; publicize IWC and its programs and products; and publicize and promote the Water Resources Research Institute Program and U.S. Geological Survey. IWC staff spends a significant portion of their time devoted to organizing, supporting and attending multiple education and outreach activities throughout the year. In addition to events, IWC staff prioritizes maintaining an effect web and social media presence.

Iowa Water Conference

The predominant Iowa Water Center information transfer product is the Iowa Water Conference, which was held March 2-3, 2015. The 2015 event was the 9th annual occurrence and had a theme of "Currents & Currencies: Trends and Motivators for Better Water Management." The conference has enjoyed stable participation rates the past several years, with 301 paid attendees, 53 attendees at the option workshop, 26 exhibitors, and 35 poster displays. Evaluations were positive; the highlight of the conference was a plenary presentation from the Director of the Agricultural Law Center at Drake University, Neil Hamilton, on the Des Moines Water Works lawsuit (a well-known active case in which a public utility sued three counties upstream for polluting drinking water supply through excessive agricultural nutrient runoff). Additionally, a session was held at the close of the conference to produce a white paper that identified priorities for water management as identified by attendees at the conference.

Virtual Erosion Symposium

On February 24, 2016, the Iowa Water Center hosted a virtual soil erosion symposium via webinar with national and international participants. The goal of the symposium was to obtain an overview of current erosion research, including expansion of the Daily Erosion Project and linking phosphorus to this project, ephemeral gully erosion, stream bank and bed erosion, recent updates of RUSLE2 technology, and recent updates of WEPP technology. This event was a compliment to the 7th International Symposium on Gully Erosion. Webinars were recorded and are available on the Iowa Water Center website.

Getting into Soil and Water

The 2015 edition of the publication *Getting into Soil and Water*, produced with the Soil and Water Conservation Club at Iowa State University, was released at the Iowa Water Conference in 2015. This 35-page publication contains articles from 24 authors, including IWC Director Rick Cruse, and IWC Advisory Board members Tom Isenhart and Mary Skopec. It is available for download from http://www.water.iastate.edu/content/getting-soil-water. The 2015 publication was distributed to approximately 2000 individuals, including Iowa Water Conference attendees, high school science and vocational agriculture teachers, attendees to the 2015 Iowa Environmental Council annual conference, potential students to the Agronomy program at Iowa State University, and handed out at various conferences where IWC was an exhibitor.

Speaking engagements

Iowa Water Center Director Rick Cruse was invited to give several presentations during this reporting period, including:

April 1, 2015. Cost of soil erosion. USDA NRCS 2015 Spring Certified Crop Adviser Update. Paynesville, MN.

April 13, 2015. Topsoil Depth Effects on Crop Yields And Weather Impacts. European Geosciences Union. Vienna, Austria.

May 13, 2015. Making Progress with Water, Energy, and Soil. National Adaptation Forum. St. Louis, MO.

June 3, 2015. The Encouraging/Discouraging Aspects of Agroforestry in a Changing Agriculture. North American Agroforestry Conference. Ames, IA.

July 9, 2015. Is Soil and Water Degradation Inevitable? Don’t bet your life on it. Alumni Brown Bag Luncheon. Ames, IA.

September 17, 2015. Is Soil and Water Degradation Inevitable? Ames Golden Kiwanis Club. Ames, IA.

September 28, 2015. Irrigation and Agriculture in Uruguay? 3rd Inter-Regional Conference on Land and Water Challenges. Colonia, Uruguay.

September 30, 2015. Daily Erosion Project. Instituto Nacional Investigacion Agropecuaria. Colonia, Uruguay.

October 5, 2015. Is Soil and Water Degradation Inevitable? Ames Rotary Club. Ames, IA.

November 19, 2015. Soil Erosion, how much is really happening. Sustaining Our Iowa Land (SOIL): the Past, Present and Future of Iowa’s Soil and Water Conservation Policy. Drake University. Des Moines, Iowa.

January 27, 2016. Daily Erosion Project: Real time inventory of soil erosion and water runoff. University of Wisconsin, Madison, WI.

February 17, 2016. Threats to Water Quality: What does the future hold? Central Iowa Sierra Club. Des Moines, IA.

Iowa Water Center Program Coordinator Melissa Miller spoke at the Water Resources Coordinating Council meeting on the 2015 Iowa Water Conference Water Priorities White Paper on September 11, 2015.

Conference planning, exhibiting, and attendance

The Iowa Water Center and its staff assisted in planning and/or exhibiting at various events during the reporting year. At each event, staff identified themselves as Water Center representatives and shared information about IWC and its products. These events include:

-USGS Iowa Water Science Center stakeholders meeting (attendee); April 1, 2015.
-Conservation Districts of Iowa Annual Conference (exhibitor); September 1-2, 2015; Altoona, IA.
-Iowa Environmental Council Annual Conference: Elevate: Creating an Environment of Action (exhibitor); October 2, 2015; Des Moines, IA.
-Sustaining Our Iowa Land Conference (attendee); November 19-20, 2015; Des Moines, IA.
-Soil Health Conference (moderator); February 2-3, 2016; Ames, IA.
-Prairie Lakes Conference (core planning committee member); to be held August 11-12, 2016; Okoboji, IA.

IWC staff also attended various meetings throughout the year, including those of watershed organizations and for research projects.

Web presence

The Iowa Water Center recognizes the importance of an effective web presence. To that end, IWC maintained an engaging website, bi-monthly electronic newsletters, and social media accounts on Twitter and Facebook.

Website: During the reporting period, IWC had 4,652 unique visitors to the website (water.iastate.edu), an increase of nearly 26% from 2014-2015. The average session duration was 2:18 with an average 2.45 pages viewed per session.

Newsletter: Newsletters were released the 2nd and 4th Thursday of each month during the reporting period for a total of 23 newsletters. At the beginning of the reporting period, the newsletter had 126 subscribers with a 54% open rate and 30% click-through rate. The last newsletter in the reporting period had 185 subscribers with a 42% open rate and a 12% click-through rate.

Twitter: At the end of the reporting period, IWC's Twitter account had 585 followers, gaining 120 followers throughout the year.

Facebook: IWC started the reporting period with 166 likes on Facebook and gained 78 likes during the year, ending at 244.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	1	0	0	0	1
Ph.D.	0	1	0	0	1
Post-Doc.	2	2	0	0	4
Total	4	3	0	0	7

Notable Awards and Achievements

Victoria Walker, the graduate student supported by Dr. Brian Hornbuckle's 104(b) project, was selected to receive a NASA Earth and Space Science Fellowship which will support her through her PhD work. 73 awarded out of 425 submitted (17% success rate). Proposal title is "A New Approach for Retrieving Soil Moisture from SMAP over the Corn Belt.”